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1. Introduction. The land-use peak discharge method was developed in 1937 at the Appalachian Forest Experiment Station, Asheville, North Carolina, and was used to determine the influence on discharges from flood contributing areas of improved land-use and the use of small surface structures.

In January 1938 the method was presented in a paper "The Influence of Planned Watershed Management on Agriculture, Stream Regulation, and Flood Control" by the writer. This paper presented a general formula for estimating the amount of surface run-off or proportionate part contributed by each land-use type area[1/] to the maximum peak discharge, and the probable reduction that may be expected in the peak discharge by an improved land-use program with the use of small surface structures, such as terraces, contour-trenches, contour furrows, or lister furrows.

The method is based upon the equation $q_n = KJ_n a_n$, and the assumption that the peak discharge from a given land-use type area is an amount J times as great as the peak discharge from the land-use type area discharging the lowest peaks within the drainage and which has a J run-off coefficient assumed as unity.

1/ An area with uniform land-use or cover type such as: well forested, poorly forested, pasture lands, abandoned farm lands, cultivated land, denuded lands, etc.

This method is being used as one phase of hydrologic studies in progress on the following detailed flood control surveys: Coosa River in Georgia, Fountain River and Cherry Creek in Colorado.

2. Basis of method. The method is based upon the assumption that a full-area flood or surface run-off occurred in all parts of the drainage and that the peak discharge is built up by the accumulation of surface run-off from each land-use type area, i.e., all lands contributed an amount of water to the peak. Thus, each land-use area, regardless of position, location, size and number of individual areas comprising a given land-use type or homogeneous area, contributed run-off to the peak discharge. The peak, however, is not the accumulation of the maximum run-off from each land-use area, but is an amount, be it small or great, from each area. This amount, however, is considered as a quantity J times as great as the amount from the land-use type area discharging the lowest peaks within the drainage and which has a J run-off coefficient assumed as unity. As each land-use area contributes run-off to the peak discharge, this amount may be expressed in terms of a proportionate part of the peak in c.s.m. (cubic feet per second per square mile) on the basis of total drainage area A.

3. Factors used in the equation, $q_n = KJ_na_n$. To estimate the amount of run-off, or the proportionate part, contributed to the peak discharge by each land-use type area, due to a flood producing storm, the equation $q_n = KJ_na_n$ was developed with factors assigned as follows:

a = area in square miles for a given land-use type n.

The total drainage area $A = (a_1+a_2+a_3+a_n)$.

n = subscript symbol denoting an area with uniform land-use or cover type conditions, usually referred to as a land-use area.

J = Run-off coefficient[2/]—Relation of run-off from a given land-use area to run-off from the area (well forested) discharging the lowest peak within the drainage assumed as unity. This area in referred to as the unit area. The J's for areas in which varied precipitation amounts occur must be corrected to a common base. The J's are estimated on the basis of observations made in the field during rainstorms; by judgment of those familiar with run-off from various land-use conditions; by infiltration studies and hydrologic data now available from experimental watersheds; and by small drainages representing various land-use conditions.

q = The amount of run-off or proportionate part of the peak discharge Q[3/] for the drainage, contributed by a given

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[2/] Hydrologic studies at the Appalachian Forest Experiment Station, Ashevills, N.C., consisting of peak discharge-area relation curves, show J's or peak discharge relations for given land-use type areas, which range from one to 50 times as great as the peak discharges from well forested areas.

[3/] Peak discharge Q must be a known value obtained by actual measurement. It is obtained from streamflow gaging records, is assumed or estimated for a given flood magnitude by either the unit hydrograph method or the modified rational run-off method.

land-use type area a_n in c.s.m. on basis of total drainage area A. The peak discharge $Q = (q_1+q_2+q_3+q_n)$.

K = A drainage area coefficient for the entire drainage, which is a conversion relation between the discharge q for a given land-use area, which involves size of area, run-off relation J, and is influenced by the hydrologic conditions of the entire drainage. The K is determined by dividing the peak discharge Q by the summation of all the $(A_n J_n)$ values for the drainage.

Thus, $K = \left[\dfrac{Q}{(a_1J_1) + (a_2J_2) + (a_nJ_n)}\right]$

K will increase when the maximum discharge increases and will decrease when the drainage area increases.

From the above factors an equation for the peak discharge may be written:

$$Q = K\Sigma\,(a_nJ_n)$$

4. Determination of reduction in peak discharge. The probable reduction that may be expected in the peak discharge after an improved land-use program (management and installation of land surface structures, strip cropping and contour tillage) is determined by the amount that the J's (run-off coefficients) can be reduced when the drainage is exposed to a similar design flood storm as that used to determine J coefficients before changes were made in the land-use areas. Little j's represent the run-off coefficient for the improved land-use program. These j's

are estimated on the basis of observations made in the field during rainstorms; by judgment, infiltration studies and some experimental data from small drainages.

The amount of run-off or proportionate part contributed to the peak discharge by each land-use area after an improved land-use program is designated by the symbol q', and is the product of the ratio factor (j ÷ J) and the c.s.m. value (KJa).

The reduced peak discharge Q' in c.s.m. is equal to the summation of all the new land-use area q''s. Thus,

$$Q' = (q'_1 + q'_2 + q'_3 + q'_n)$$

and the amount of reduction is: $Q - Q'$

5. <u>An example</u>. The headwaters area of Fountain river, consisting of Monument Creek and Templeton Gap drainage, which is located north of Colorado Springs, Colorado, will be used to demonstrate the application of the land-use peak discharge method as here presented.

Design factors:

Total drainage area = 239.1 square miles. The one percent expectancy peak discharge (discharge of a 100-year frequency) is equal to the 1935 flood peak plus 30%

Q = 50,000 + 30% = 65,000[4/] c.f.s. or 272 c.s.m.

4/ Three floods have occurred during the last 75 years which have discharged peaks of 50,000 c.f.s. at Colorado Springs, above the confluence of Monument Creek and Fountain Creek. It is, therefore, believed that a peak discharge of 65,000 c.f.s. could be expected as the expectancy one percent flood. This amount is 30% greater than the 50,000 c.f.s. flood of 1935.

Design flood storm for 24 hour period:

High mountain section—4 inches.

Average for eastern front range section—7 inches.

Valley and eastern plains—10 inches.

Description of land-use type areas:

F_1—Good forest cover of pine, fir, spruce, aspen, and cedar above 8,000 ft. elevation with most of the area in national forest; rough broken areas with some barren rock outcrops; some detention dams; infiltration rates moderate to rapid; slopes over 20% predominant with some 10-20%; and the design storm estimated at 4 inches (24 hours).

F_2—Fair forest cover of pine, fir, spruce, aspen, and cedar below 8,000 ft. elevation with most of the area outside of the national forest along the front range mountains and foothills; moderate to rapid rate of infiltration; slopes same as F_1; design storm estimated at 7 inches.

F_3—Medium forest cover, predominantly western yellow pine, on the Arkansas-Platte river basins divide which is mostly on private land; some thin and badly cut-over areas; moderate to rapid rate of infiltration; slopes 6-10% predominant with some 10-20%; design storm estimated at 10 inches.

R_1—Range Land. Gravelly to shallow gravelly upland soils on undulating to hilly topography with grama, sage and chaparral cover and from 20-50% overgrazed; moderate rate of infiltration; slopes 10-20% predominant with some 6-10% and 3-6%.

R_2—Range land. Predominantly sandy upland soils with some sandy alluvial soils on level to gently rolling topography with grama and bunch grass cover which is from 0-25% overgrazed; moderate to rapid rate of infiltration; slopes 0-6% predominant with some 6-10%.

R_3—Range land. Moderately heavy alluvial soils on level to gently sloping topography with grama grass 25-70% overgrazed; moderate rate of infiltration; slopes 0-6% with 0-3% predominant.

C_1—Cultivated land. All soil groups on level to 10% slope with 0-6% predominant; to remain in cultivation.

C_2—Cultivated land. Same as C_1 but to be retired to grass and solid listed; slopes 3-10% with 3-6% and 6-10% approximately evenly divided.

U —Urban centers. This area is mostly within the city of Colorado Springs and is located at the very bottom of the Monument Creek drainage basin. Infiltration rates are very low and run-off is extremely high.

Run-off from this area does not contribute much to the flood peak of Monument Creek which causes flood damages to Colorado Springs. The water from this area is in the river channels and out of the basin long before Monument Creek crests at Colorado Springs.

The example presented in table 1 shows the following estimated reduction in the peak discharge (272 c.s.m.) for the expectancy one percent flood:

Immediately after operations program	— 67.2 c.s.m.	or 24.7%
10 years " " "	— 83.9 " " "	" 30.8%
20 years " " "	— 94.0 " " "	" 34.6%

All computations were made with a slide rule. Use-description of the various columns in the table are as follows:

Column 1.—Symbol designating the various land-use type areas.

Column 2.—Size of land-use type areas in square miles.

Column 3.—Size of land-use type areas as percent of total drainage basin.

Column 4.—Design storm in inches for a 24 hour period over the drainage basin. This storm is expected to produce the one percent flood from the basin.

Column 5.—The J run-off coefficient amounts for the various land-use type areas when exposed to a uniform storm over the entire basin.

TABLE 1. REDUCTION IN PEAK DISCHARGE THROUGH AN IMPROVED LAND USE PROGRAM—MONUMENT CREEK AND [illegible] DRAINAGE ABOVE COLORADO SPRINGS, COLO.

Drainage area = 239.1 sq. mi.
Land-use peak discharge formula: $q_n = Kj_na_n$

$$K = \left[\frac{Q \text{ (peak discharge)}}{(a_1j_1)+(a_2j_2)+(a_nj_n)}\right] = \frac{272}{854.7}\,1/ = 0.3182$$

Estimated peak produced by design storm - 65,000 c.f.s. or 272 c.s.m.
Reduction in peak discharge:
Immediately after treatment = (272-204.8) = 67.2 c.s.m. or 24.7%
10 years after treatment = (272-188.1) = 83.9 c.s.m. or 30.8%
20 years after treatment = (272-178.0) = 94.0 c.s.m. or 34.6%

Present Drainage Area, Characteristics Before Treatment "1930"								Treatment	Run-off characteristics after treatment								
									Immediately			10-year Period			20-year Period		
Land use	Size of Areas: a	Size of Areas: Pc. of Total	Design Storm (24 hrs)	J Run-off Coefficients: Uniform storm type	J Run-off Coefficients: Design Storm	Value ja	Value q (Kja)	5-yr. operations program	Run-off coef. j	Ratio Factor j-j	Value q (qj-j)	Run-off coef. j	Ratio Factor j-j	Value q (qj-j)	Run-off coef. j	Ratio Factor j-j	Value q (qj-j)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Symbol "n"	Sq. mi.	Pc.	Inches	Amt.	Amt. 2/	Amt.	c.s.m.	Kind	Amt.	Pc.	c.s.m.	Amt.	Pc.	c.s.m.	Amt.	Pc.	c.s.m.
P_1	83.9	35.1	4	1.0	1.0	83.9	26.7	Management	1.0	1.00	26.7	1.0	1.0	26.7	1.0	1.00	26.7
P_2	27.0	11.3	7	1.8	2.7	72.9	23.2	Management	2.5	.93	21.6	2.2	.81	18.9	2.0	.75	17.4
P_3	31.8	13.3	10	1.6	4.0	127.2	40.5	Management	4.0	1.00	40.5	3.4	.85	34.4	3.0	.75	30.4
R_1	49.4	20.7	10	[illegible]	6.0	296.4	94.3	Lister furrows & Management	3.5	.58	54.7	3.2	.53	50.0	3.0	.50	47.2
R_2	23.3	11.3	10	2.0	6.0	141.5	45.0	16" low & lister furrows & Mgt.	3.0	.60	27.0	2.7	.54	24.3	2.5	.50	22.5
R_3	2.3	1.0	10	2.3	7.0	16.1	5.1	Lister furrows Management	4.5	.65	3.3	4.2	.60	3.1	4.0	.57	3.1
C_1	11.3	4.7	10	3.2	8.0	90.4	28.8	Str. Crop & Contour Till.	7.0	.87	25.1	7.0	.87	25.1	7.0	.87	25.1
C_2	2.2	0.9	10	3.2	8.0	17.6	5.6	Solid listed	4.5	.55	3.1	4.2	.52	2.9	4.0	.50	2.8
U	2.9	1.2	10	1.3 3/	3.0	8.7	2.8	None	3.0	1.00	2.8	3.0	1.00	2.8	3.0	1.00	2.8
Totals	239.1	100.0				854.7	272.0				204.8			188.1			178.0

1/ The figure 854.7 is the summation of the Ja values--total for Column 7.

2/ J coefficients are corrected to a common base with area P_1 as the base area.

3/ Under most conditions the J coefficient for urban centers will be 5-10 times as great as j's from well forested areas. As this area is mostly in the city of Colorado Springs and at the bottom of Monument Creek drainage basin most of the run-off is in the river channels and away down stream before Monument Creek crests. Therefore, the J value is extremely low.

Column 6.—The J run-off coefficient corrected to a common base. When the design storm varies greatly in rainfall amounts over various portions of the basin it is necessary to correct all J's[5] to a common base, i.e.,

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5/ In the Monument Creek drainage basin the high mountainous front along the western boundary is forested and the run-off, both peak discharges and annual discharges, is relatively low. This mountainous area discharges lower peaks than any other land-use type area within the Monument Creek basin. It was found from a hydrologic study of the basin (raingage records) that the recharge, produced by the design flood storm, for a 24-hour period would range from 10 inches in the valley and plains to only four inches in areas above 8,000 feet elevation. As the recharge over the basin is not that of a uniform storm, it is necessary to correct to a common base all J run-off coefficients for all land-use type areas within the basin (table 1, column 6). The mountainous area is divided into two rainfall zones or land-use areas: F_1—a four inch zone for the area above 8,000 feet elevation, designed as the unit area; and F_2—the seven inch rainfall area below 8,000 ft. elevation. This area includes the foothills which are sparsely covered with trees and the peak discharges are about 50% higher than the peaks from area F_1, both areas exposed to same uniform storm. The range land (R_1) located at bottom of foothill and valley and in the 10 inch rainfall zone discharges peaks, produced by the uniform storm, that are about 2.4 times as great as the peaks from area F_1. The following J relations exist when all three areas F_1, F_2 and R_1 are exposed to the same type of rainstorm:

$$J_{F_1} = 1, \; J_{F_2} = 1.5, \text{ and } J_{R_1} = 2.4$$

The J coefficients become considerable higher when exposed to the design flood storm. As area F_2 received a recharge 1.75 (7 inch rainfall) times as great as F_1 (4 inch rainfall) the peak discharge from F_2 is at least from 1.5 to 2 times as great as from F_1, and as the recharge on area R_1 is 2.4 as great as on area F_1 the peak will increase in about the same proportion as the increase in recharge. This assumption was found to hold true on hydrologic experimental drainages in the southern Appalachian region.

Thus, on this basis the J's were corrected for all land-use type areas (table 1, column 6).

to the unit area or the land-use type area that discharges the lowest peak discharges when exposed to a uniform type of storm. The J's will either increase or decrease from their hydrologic amounts under a uniform storm condition.

This increase or decrease will depend upon the rainfall amount over the unit area as compared with the amounts over the other land-use type areas.

Column 7.—The value of J for each land-use type area. This amount is a product from columns 2 and 5. The total for the column is used to determine the drainage area coefficient K.

Column 8.—The amount of run-off, or the proportionate part, contributed to the peak discharge by each land-use type area. The total for the column in the peak discharge is c.s.m. for the one percent flood.

Column 9.—Kind of treatment applied to the land by a U.S.D.A. erosion and flood control operations program.

Column 10.—The J run-off coefficient amount for each land-use type area immediately after treatment or completion of the operations program when exposed to the design flood storm.

Column 11.—The ratio factor ($j \div J$) or the percent of change in the peak discharges for each land-use type area due to the improved land-use changes and the operations program.

Column 12.--The amount of run-off, or the proportionate part, contributed to the peak discharge by each land-use type area after installation of the operations program. The individual amount is a product from Columns 8 and 11. The total for the column is the peak discharge in c.s.m. for the one percent flood immediately after the operations program. The reduction in peak discharge for the one percent flood is the difference between the totals of columns 8 and 12 (Col. 8 - Col. 12).

Columns 13 to 18, inc.--These columns are similar to columns 10, 11, and 12, and represent the run-off characteristics after 10 and 20 year period from completion date of the operations or watershed improvement program.

6. <u>Discussion</u>. The writer is familiar with several methods or ways in which the probable reduction in run-off, due to an improved land-use program, may be estimated. To his knowledge the land-use peak discharge method offers most favorable possibilities, especially now that infiltration studies are in progress on watersheds where detailed surveys are being made. These studies should furnish the basis for selecting numbers for the J run-off coefficients.

This method has been checked against the method generally used by Dr. C. S. Jarvis to estimate the reduction in peak discharges, due to an improved land-use program, and found to give approximately the same result.

The Jarvis method differs from the land-use peak discharge method as it first deals with the total run-off under the flood hydrograph before improved land-use treatments are applied; and second, the total run-off, retardation in time of peak crest and the retardation in total duration of run-off after improved treatments are applied. The land-use peak discharge method deals directly with the peak discharge and the amount of run-off or proportionate part contributed by each land-use type area to the peak both before and after treatment. In both methods, however, the total run-off and the J run-off coefficients are estimated in the same manner by judgment of those familiar with run-off from various land-use conditions, knowledge of infiltration capacities of various soils and cover type conditions, and the amount of water that can be retained in land surface structures and then allowed to infiltrate into the ground.

The peak method is best adapted to tributary drainages less than 100 square miles and where the land-use type areas are scattered throughout the drainage on homogeneous soil areas. When this method is used to estimate peak discharges from large drainage basins all major drainage tributary to the main streams should be handled separately and the peak estimated for each drainage at or near its

confluence with the main stream. A study of streamflow for the entire basin is essential involving channel storage, stream synchronization, time of concentration, and the routing of the flood down the major streams and main stem.

The writer wishes to emphasize the fact that the demand for hydrologic data from various types of drainage basins, representing uniform and non-uniform land-use areas or cover type conditions, is rapidly increasing and that more hydrologic data, including infiltration indices for various homogenous areas, from completely controlled drainages are needed. The demand has become acute as a result of the Flood Control Act of June 22, 1936, in which Congress charges the Department of Agriculture with the investigations of watersheds and measurements for run-off and water-flow retardation, and soil erosion prevention for flood control purposes. Hydrologic data dealing primarily with the effects of land-use conditions on streamflow behavior are needed before the Department of Agriculture can successfully fulfill their obligation of submitting a flood control program involving improved land-use changes and the use of small land surface structures.